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Applicant: Rafael STORZ et al.
Title: METHOD FOR ILLUMINATING AN OBJECT WITH LIGHT FROM
A LASER LIGHT SOURCE
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**TRANSMITTAL OF ACCURATE TRANSLATION
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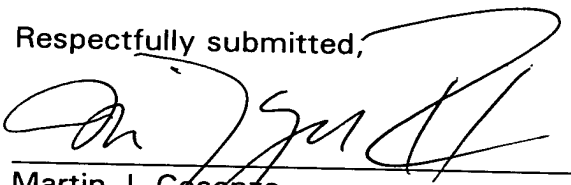
Sir:

Submitted herewith please find a translation of applicants' priority document, German Patent Application No. 100 42 114.8, filed August 28, 2000. The undersigned represents that this translation is accurate.

Respectfully submitted,

September 15, 2003
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relating to a

**“Method for Illuminating an Object with Light from
a Laser Light Source”**

The present invention relates to a method for illuminating an object with light from a laser light source, preferably in a confocal scanning microscope.

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Laser light sources are used in a large number of devices and applications for illuminating objects. In this case, in particular, the advantages of high coherence length and excellent beam profile, i.e. parallelism of the light radiation emitted by the laser light source, the outstanding frequency or wavelength consistency, and the monochromaticity of the light are utilized.

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The high spatial and temporal coherence of laser light is due to the stimulated emission by the optical medium in the laser, and has the effect that both the individual wavelets and the waves emitted at different times interfere virtually without limitation. The coherence length of a laser is related to the linewidth $\delta\nu$ by the equation

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$$= c / (2 \pi \delta\nu)$$

where c is the speed of light. Accordingly, a linewidth $\delta\nu=100$ MHz corresponds to a coherence length ≈ 0.5 m. The linewidth, or the coherence length, of a laser light source also depends very greatly on the time interval over which the linewidth or the frequency of the laser light source is measured. For example, with large integration times, a laser oscillator exhibits long-term effects which are proportional to the time interval of the measurement and are caused by linear drift of the laser oscillator, for example due to temperature variations.

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For some applications, however, a high coherence length is a problem since it can lead to the formation of undesired interference phenomena in the optical

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beam path. Especially in confocal scanning microscopy, such interference phenomena can induce imaging aberrations.

5 It is therefore an object of the present invention to provide a method with which the coherence length of the laser light can be reduced, so that disruptive interference phenomena can be substantially eliminated. Should interference phenomena nevertheless be formed, these are to be influenced in such a way that they have no effect on the detection.

10 The method according to the invention of the generic type achieves the above object by the features of Patent Claim 1. According thereto, such a method is characterized in that the phase angle of the light field is varied by a modulation means in such a way that interference phenomena do not occur in the optical beam path, or occur only to an undetectable extent, within a predeterminable
15 time interval.

According to the invention, it has been recognized for the first time that disruptive interference phenomena in the optical beam path can be avoided if the coherence length of the light emitted by the laser light source is less than
20 the optical path in the illumination beam path. Even if disruptive interference phenomena are formed in the optical beam path, a suitable modulation means can be used to vary these suitably so that within a predeterminable time interval, which may depend on a detection instrument, the interference phenomena per se are not detectable.

25 With the aid of the method according to the invention, it is particularly advantageously possible to use solid-state laser systems, including semiconductor or diode lasers. It is thereby also possible to use narrow-band gas lasers. These laser systems are not so complicated to deal with, and they
30 are less expensive and more compact.

Likewise, frequency-doubling laser systems and OPOs (optical parametric oscillators) could be used for confocal scanning microscopy.

Several variants are provided for practical embodiment of the method according to the invention.

5 In a first variant, an EOM (electro-optical [sic] modulator) is employed as the modulation means. This EOM is arranged directly downstream of the laser light source, so that the laser radiation emitted by the laser light source passes through the EOM. The EOM can vary the phase angle of the light field in such a way that broadening of the spectral linewidth of the laser radiation is thereby achieved. In this case, a noise signal, a periodic signal or a stochastic signal
10 could be applied to the EOM, so that spectral components are superimposed on the laser light and so that the linewidth of the laser radiation is increased to the linewidth of the superimposed signal.

15 In a second variant, a mirror, a lens or a beam splitter is used as the modulation means. This modulation means is also arranged downstream of the laser light source. It is mounted in such a way that it also vibrates or oscillates as a result of vibrations or oscillations of the optical structure or of the casing. In the simplest case, this could involve a lens which is merely placed, but not fixed, in a lens frame. The slight vibrations or oscillations of the
20 device, which are in any case induced, for example, by fans, cause the lens itself to oscillate. The mirror, the lens or the beam splitter could also be moved with the aid of a control element. The control element could, for example, be a piezo element to which a corresponding control signal is applied.

25 As a result of the oscillation, vibration and/or movement of the modulation means, the optical path of the light radiation can be stochastically varied, i.e. the length of the optical path is thereby stochastically varied. Owing to the stochastic variation of the optical path, interference phenomena which may occur in the predetermined time interval are also modified, so that an integral
30 detector - a detector which, for example, records the cumulative sum of the light intensity within the predetermined time interval - does not detect the interference phenomenon per se, and accordingly the measurement result is also not disruptively influenced.

- In a third variant, provision is made for the modulation means to influence the laser light source. For instance, a modulation means could switch the laser light source on and off. This process of switching on and off would need to take place at least once within the predeterminable time interval. The
- 5 switching on and off could be performed by corresponding modulation of the pump current of the laser, specifically, for example, if the modulation means periodically interrupts the pump current. More generally, provision could be made for the modulation means to influence the pump current of the laser. In this case, for example, the pump current of a diode laser could be sinusoidally
- 10 modulated so that the light power emitted by the diode laser is also periodically modified. In this way, it could be possible to vary the wavelength of the light emitted by the diode laser, which should be taken into account in a practical application.
- 15 As an alternative to this, provision is made to influence the intensity of the laser light source. This could be done using conventional methods for influencing intensity in laser light sources, for example by Q-switching or cavity dumping.
- 20 Furthermore, the modulation means could influence the laser resonator or the optical medium of the laser. In practical terms, provision could be made for the modulation means to be configured as a piezo element which moves and/or deforms at least one component of the laser resonator and/or the optical medium. In practical terms, the piezo element could be connected directly or
- 25 indirectly to the optical medium, for example to the laser crystal. Using corresponding circuit interconnection of the piezo element, its extension is then transmitted to the optical medium and the laser is hence perturbed from its normal operation.
- 30 More generally, provision is made for a signal to be applied to the modulation means. The signal could be a noise signal, a periodic signal or a stochastic signal. Accordingly, for example, a noise signal could be applied to the modulation means configured as an EOM and a stochastic signal could be applied to the modulation means configured as a control element. A noise
- 35 generator could be used to produce the noise signal.

In practical terms, provision is made for the method according to the invention to be used in a confocal scanning microscope. This could, for example, involve a confocal scanning microscope for inspecting products in the semiconductor industry. A confocal fluorescence laser scanning microscope or
5 a biconfocal scanning microscope would also be feasible.

The predeterminable time interval in which the modulation means varies the phase angle of the light field, when using the method according to the invention in conjunction with a confocal scanning microscope, would need to
10 be selected so that it is shorter than the pixel clock. The term "pixel clock" in confocal scanning microscopy means the time interval involved when the light intensity values measured during scanning the object are cumulatively allocated to a pixel. Preferably, the predeterminable time interval is selected
15 so that it is shorter than the time interval corresponding to half the pixel clock, so that the interference phenomena which may occur in the optical beam path are varied whenever possible during the predeterminable time interval. As a result of this, the interference phenomena do not occur to a detectable extent.

20 The modulation of the phase angle of the light field is synchronized with the scanning process of the confocal scanning microscope. This is useful, in particular, with a view to specifying the time interval, i.e. for example the pixel clock, for successful implementation of the method according to the invention. More generally, the modulation of the phase angle of the light field can be
25 synchronized with the object illumination process to be carried out.

A change in the wavelength of the laser light due to the modulation is advantageously taken into account by the control unit of an AOTF (acousto-optical tunable filter) or AOBS (acousto-optical beam splitter). This component
30 is provided for injecting the laser light into the optical structure, or the confocal scanning microscope. The injection by an AOTF or AOBS is in this case normally adjusted only for a limited wavelength range of the laser light so that, in the event of a change in the wavelength of the laser light due to the modulation, the control unit of the AOTF or AOBS should be changed
35 correspondingly so as not to reduce the injection efficiency.

In a similar way, it would be conceivable for the control unit of an AOTF or AOBS, which injects the laser light, to take into account a change in the power of the laser light due to the modulation. The injection efficiency can again
5 hence be kept substantially constant.

There are, moreover, various possible ways of advantageously configuring and developing the teaching of the present invention. In this regard reference should be made, on the one hand, to the patent claims dependent on Patent
10 Claim 1 and, on the other hand, to the following explanation of the preferred exemplary embodiments of the invention with the aid of the drawing. Generally preferred configurations and developments of the teaching are furthermore explained in connection with the explanation of the preferred exemplary
15 embodiments of the invention with the aid of the drawing. In the drawing,

Fig. shows a diagrammatic representation of a confocal scanning microscope in which the method according to the invention is used.

20 The Fig. shows a confocal scanning microscope 1, in which an object is illuminated with light 2 from a laser light source 3.

According to the invention, the phase angle of the light field is varied by a modulation means 4 designed as an EOM, in such a way that interference
25 phenomena do not occur in the optical beam path, or occur only to an undetectable extent, within a predeterminable time interval.

The EOM 4 is arranged directly downstream of the laser light source 3. A stochastic noise signal 5 is applied to the EOM 4, so that laser light 2 passing
30 through the EOM 4 has a broadened spectral linewidth after its transmission and, accordingly, is injected into the confocal scanning microscope 1 as light 6 with a smaller coherence length. A noise generator 7 is used to produce the noise signal 5.

Via the connection 8, the modulation of the EOM 4 is synchronized with the scanning process of the confocal scanning microscope 1.

- 5 Lastly, it should more particularly be pointed out that the exemplary embodiments discussed above are merely used to describe the claimed teaching, but do not restrict it to the exemplary embodiments.

List of References

- 1 confocal scanning microscope
- 2 light from (3)
- 3 laser light source
- 4 modulation means, EOM
- 5 noise signal
- 6 the light varied by (4)
- 7 noise generator
- 8 Synchronization connection between (1) and (7)

Patent Claims

1. Method for illuminating an object with light (2) from a laser light source (3), preferably in a confocal scanning microscope (1),
5 characterized in that the phase angle of the light field is varied by a modulation means (4) in such a way that interference phenomena do not occur in the optical beam path, or occur only to an undetectable extent, within a predeterminable time interval.
2. Method according to Claim 1, characterized in that an EOM (4) (electro-optical modulator) is employed as the modulation means.
- 10 3. Method according to Claim 2, characterized in that the EOM (4) is arranged directly downstream of the laser light source (3).
4. Method according to Claim 1, characterized in that a mirror, a lens or a beam splitter is used as the modulation means (4).
- 15 5. Method according to Claim 4, characterized in that the modulation means (4) is mounted in such a way that it also vibrates or oscillates as a result of vibrations or oscillations of the optical structure or of the casing.
6. Method according to Claim 4, characterized in that the modulation means (4) is moved using a control element.
- 20 7. Method according to Claim 6, characterized in that the control element is a piezo element.

8. Method according to Claim 1, characterized in that the modulation means influences the laser light source.
9. Method according to Claim 8, characterized in that the modulation means switches the laser light source on and off.
- 5 10. Method according to Claim 8, characterized in that the modulation means influences the pump current of the laser.
11. Method according to Claim 8, characterized in that the modulation means influences the intensity of the laser light source.
- 10 12. Method according to Claim 8, characterized in that the modulation means influences the laser resonator or the optical medium of the laser.
13. Method according to Claim 12, characterized in that the modulation means is a piezo element which moves and/or deforms at least one component of the laser resonator and/or the optical medium.
- 15 14. Method according to one of Claims 1 to 13, characterized in that a noise signal (5), a periodic signal (5) or a stochastic signal (5) is applied to the modulation means.
15. Method according to Claim 14, characterized in that a noise generator (7) is used to produce the noise signal (5).
- 20 16. Method according to one of Claims 1 to 15, characterized by use in a confocal scanning microscope (1).
17. Method according to Claim 16, characterized in that the predeterminable time interval is shorter than the pixel clock of the confocal scanning microscope (1), preferably shorter than the time interval corresponding to half the pixel clock.

18. Method according to one of Claims 1 to 17, characterized in that the modulation is synchronized with the scanning process of the confocal scanning microscope (1).
- 5 19. Method according to one of Claims 1 to 18, characterized in that a change in the wavelength of the laser light (6) due to the modulation is taken into account by the control unit of an AOTF (acousto-optical tunable filter) or AOBS (acousto-optical beam splitter) which injects the laser light.
- 10 20. Method according to one of Claims 1 to 19, characterized in that a change in the power of the laser light (6) due to the modulation is taken into account by the control unit of an AOTF or AOBS which injects the laser light.

Abstract

The present invention relates to a method for illuminating an object with light (2) from a laser light source (3), preferably in a confocal scanning microscope (1). With the method according to the invention, it is possible to reduce the coherence length of the laser light, so that disruptive interference phenomena can be substantially eliminated. Should interference phenomena nevertheless be formed, these are to be influenced in such a way that they have no effect on the detection. The method according to the invention is characterized in that the phase angle of the light field is varied by a modulation means (4) in such a way that interference phenomena do not occur in the optical beam path, or occur only to an undetectable extent, within a predeterminable time interval.

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(Fig.)